5XTC0: Lab assignment passive components and VNA

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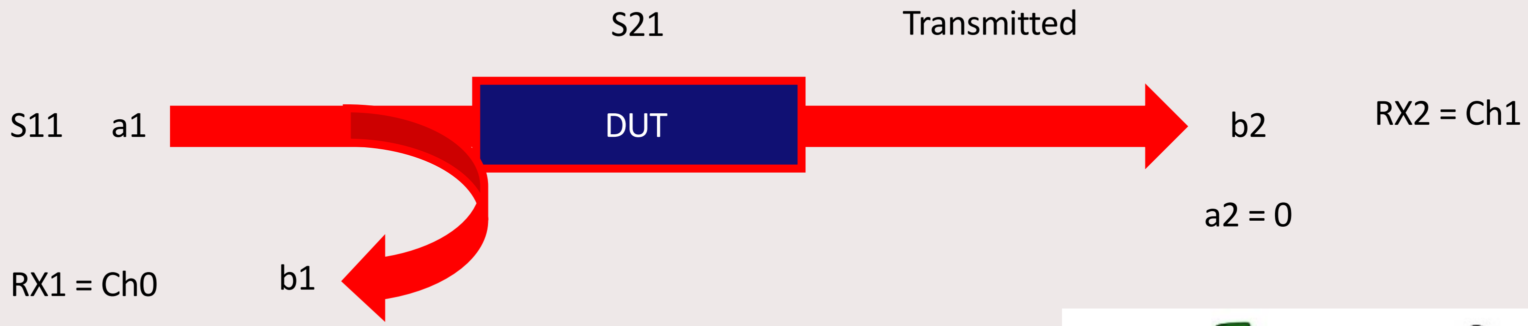
Learning goals

- **VNA basics**
- VNA measurements
- Quarter-wave stub

VNA basics



a1,b1,a2,b2 represent the forward and backward voltage travelling waves

$$S_{11} = \frac{Reflected}{Incident} = \frac{b1}{a1}\Big|_{a2=0}$$

$$S_{21} = \frac{Transmitted}{Incident} = \frac{b2}{a1}\Big|_{a2=0}$$

a1 or b1

b2

Borrowed from https://www.rtl-sdr.com/reviews-of-the-nanovna-an-ultra-low-cost-50-vector-network-analyzer/

VNA basics: which devices can we measure?

- Passive
  - Delay lines
  - Open, short, load
  - Splitter, dividers
  - **Quarter-wave stubs (Lab 2)**
  - **Antennas (Lab 3)**
  - Filters
  - Etc.
- Active
  - RFICs
  - Receivers
  - Etc.

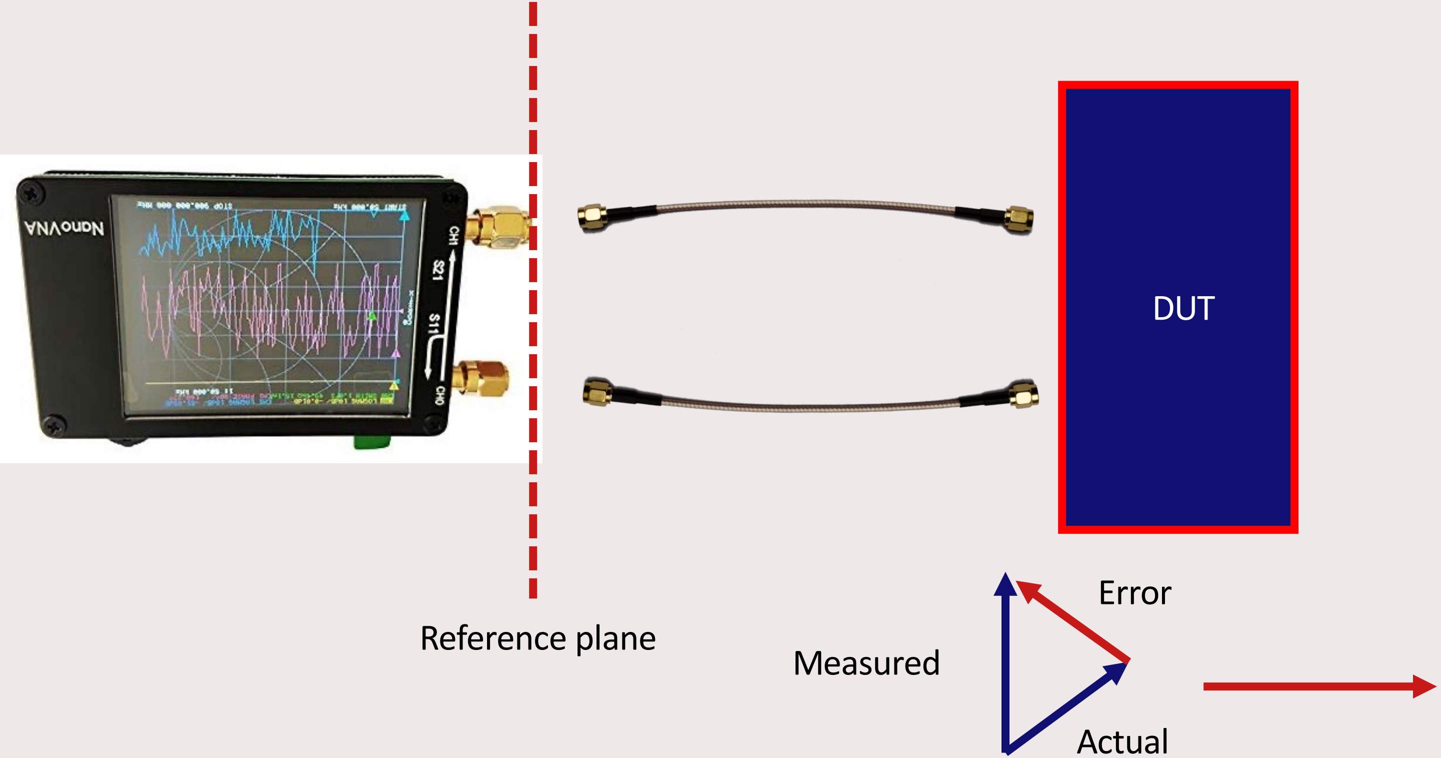
VNA basics: errors

- Systematic errors
  - Due to imperfections
  - Predictable

- Random errors
  - Time-varying (e.g. noise, connector repeatability)
  - Unpredictable

- Drift
  - Due to system changing after calibration (e.g. temperature variation)
  - Minimize by ensuring temperature stability
  - Otherwise recalibrate

Introduction SOLT calibration



Compensate for magnitude and phase

Introduction SOLT calibration

- Solution: Measure 3 standards to obtain the 3 unknown errors
- Make the standards as different as possible:
  - Short (power **reflected**)
    - $Z_{source} = Z_0, Phase = 180°$
  - Open (power **reflected**)
    - $Z_{source} = Z_0, Phase = 0°$
  - Load (power **absorbed**)
    - $Z_{source} = Z_0, V_{refl.} = 0$
- If measuring a 2-port device, SOL calibration assumes a good termination at port 2

Isolation and thru NanoVNA

SOL performed on port 1 → How do we know errors introduced in cable 2 and port 2?

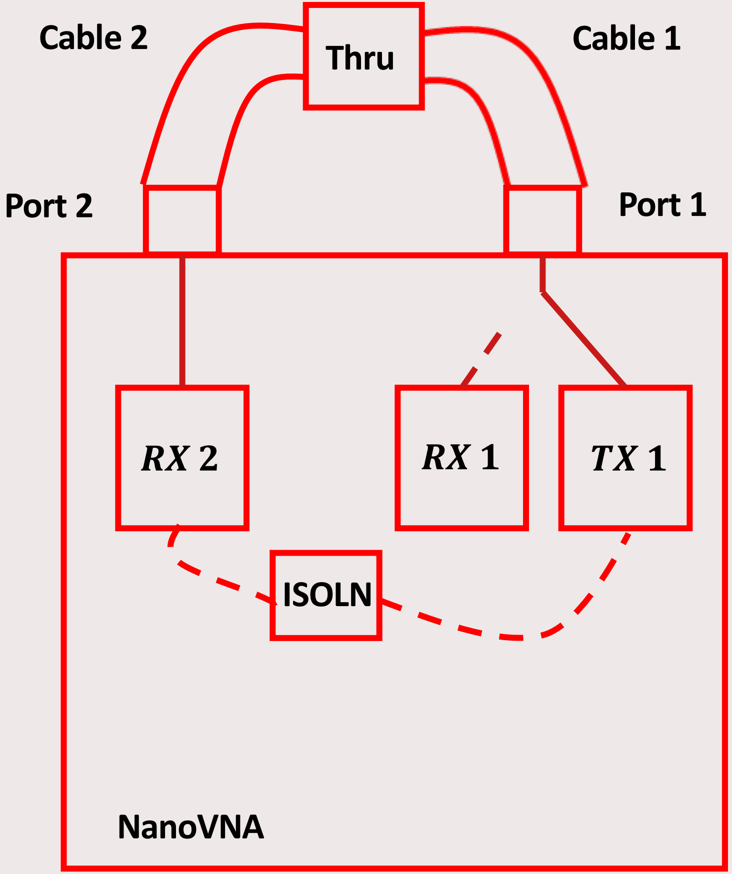
- THRU measurement

NanoVNA has only 1 transmitter → less accurate!

Cross-talk between RX2 and TX1 → influences your measurement!

What can we do about that?

- Isolation measurement (ISOLN)



Learning goals

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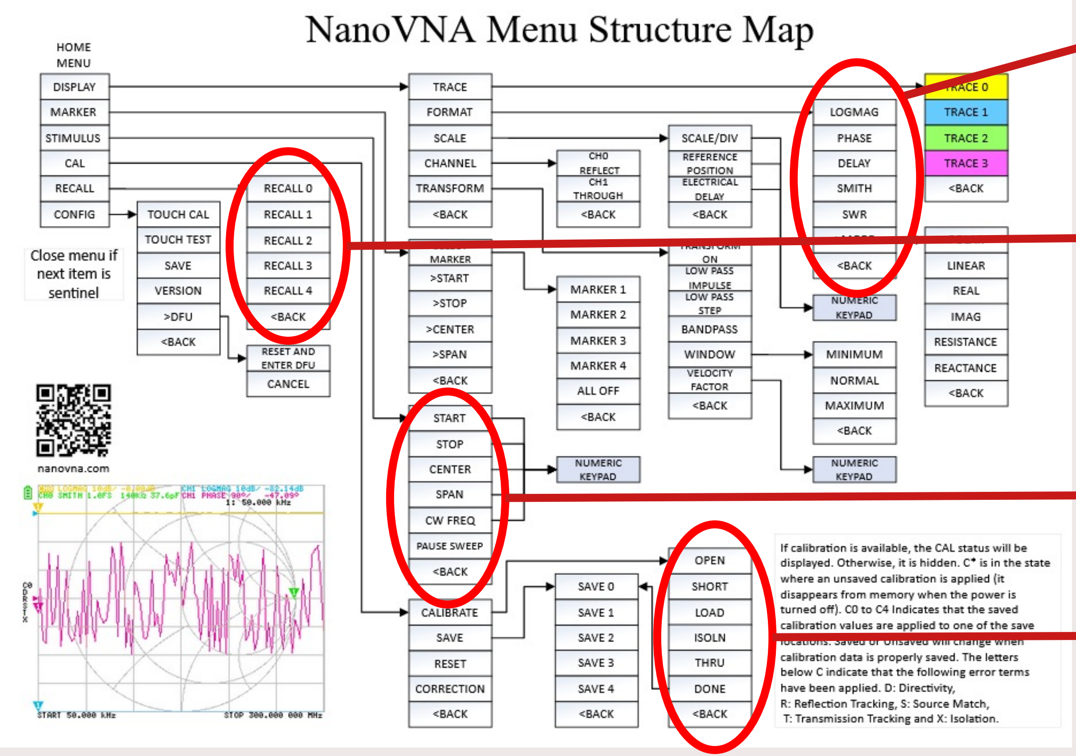
- **VNA measurements**
- Quarter-wave stub

NanoVNA: how to use it?



Visualization of magnitude and phase (LOG/MAG plot and Smith chart)

Loading Calibrated data

Setting frequency range

Calibrating your VNA

Obtained from www.nanovna.com

Setting up the NanoVNA

- Set the frequency range of interest 400 MHz – 1400 MHz
- Connect the SMA cables to the NanoVNA (take care of the cables and connectors!)
- Perform a calibration
  1. Perform an **OPEN** calibration → connect open standard to **CH0** and execute OPEN in the calibration menu
  2. Perform a **SHORT** calibration → connect short standard to **CH0** and execute SHORT in the calibration menu
  3. Perform a **LOAD** calibration → connect load standard to **CH0** and execute LOAD in the calibration menu
  4. Perform a **ISOLN** calibration → connect load standard to **CH1** and execute ISOLN in the calibration menu. CH0 can be left unconnected
  5. Perform a **THRU** calibration → connect thru standard to **CH0** and **CH1** and execute THRU in the calibration menu
  6. Execute DONE at the end of the calibration process
  7. Save the calibration data to e.g. SAVE0
  8. Recall the saved calibration data with RECALL0 (which is SAVE0).

See also https://nanovna.com/

Exporting data

Data can be exported to your laptop

- Your laptop → NanoVNASaver (Windows/Linux/IOS)
- Your mobile phone → NanoVNA web client (Android only!)

Data format is TOUCHSTONE (.s*p files)

- Touchstone is a S-parameter format which can directly be processed in Matlab for example

Exporting data

NanoVNASaver

1. Download NanoVNASaver application from CANVAS for your operating system
2. Connect the USB-C cable to your laptop and the NanoVNA
3. How to use the application → follow the instructions on https://github.com/NanoVNA-Saver/nanovna-saver
4. The exported touchstone file can be directly visualized in Matlab with *Rfplot* and *sparameters* functions

Perform the following measurements after calibration

Don’t forget to export your data!

- Measure the open and short, check the S11 and S21. What does the logmag plot show you and what does the smith chart show you?
- Measure the thru (S21 logmag) and the load (S11 smith chart) and export your data to your laptop
- Try moving the cables in all directions and perform the measurement again, how much have the measured values changed?

- *How can you verify that the calibration was performed correctly?*
- *Can you give a rough estimate of the magnitude/phase/impedance errors after moving the cables?*

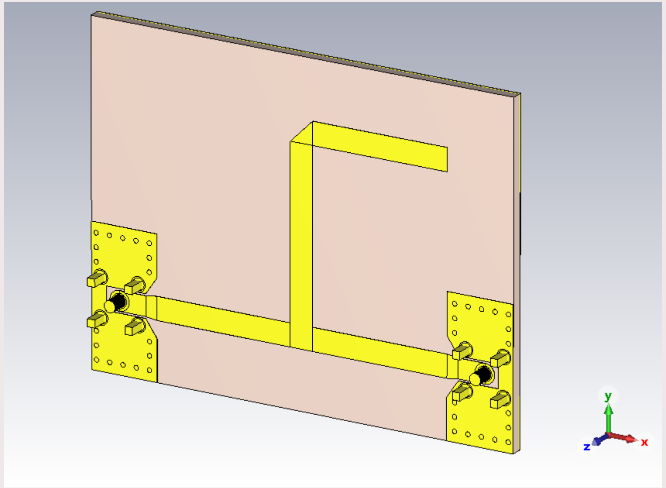
Learning goals

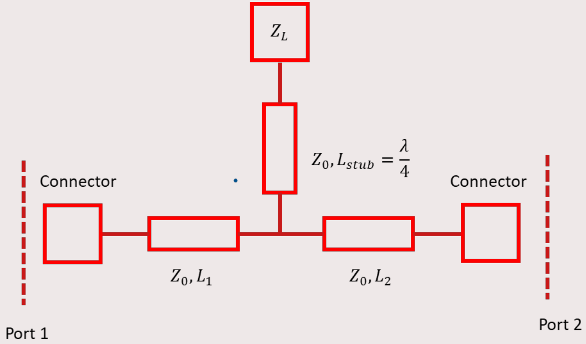
- VNA basics
- VNA measurements
- **Quarter-wave stub**

Lab assignment

Passive component → quarter-wavelength stub

$$Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)} \longrightarrow Z_{in} = \frac{Z_0^2}{Z_L}$$



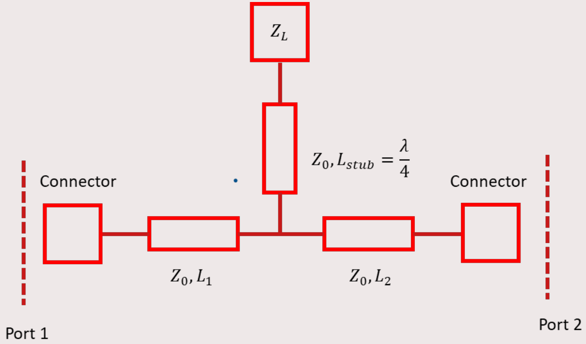


What happens with the reflection coefficient for an open or short load?

Lab assignment

Open-circuited stub

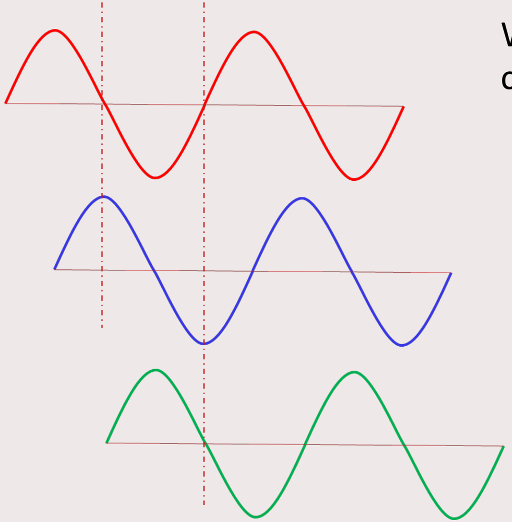
$$Z_{in} = \frac{Z_0^2}{Z_L}$$



Incident wave

Wave arriving at $Z_L \; (l = \frac{\lambda}{4})$

Reflected wave $\left(l = \frac{\lambda}{2}\right)$



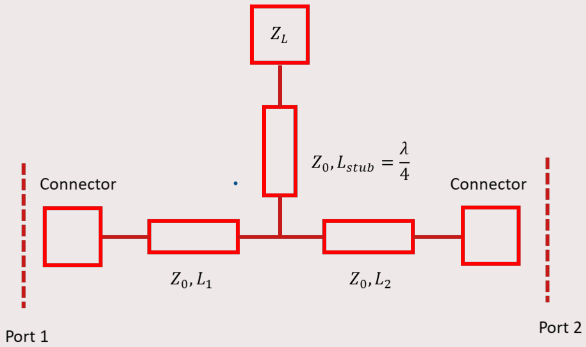
Waves cancel!

What is the reflection coefficient?

Lab assignment

Short-circuited stub

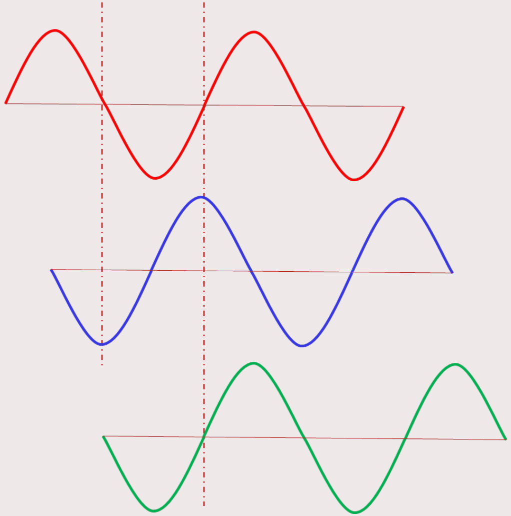
$$Z_{in} = \frac{Z_0^2}{Z_L}$$



Incident wave

Wave arriving at $Z_L\ (l = \frac{\lambda}{4})$

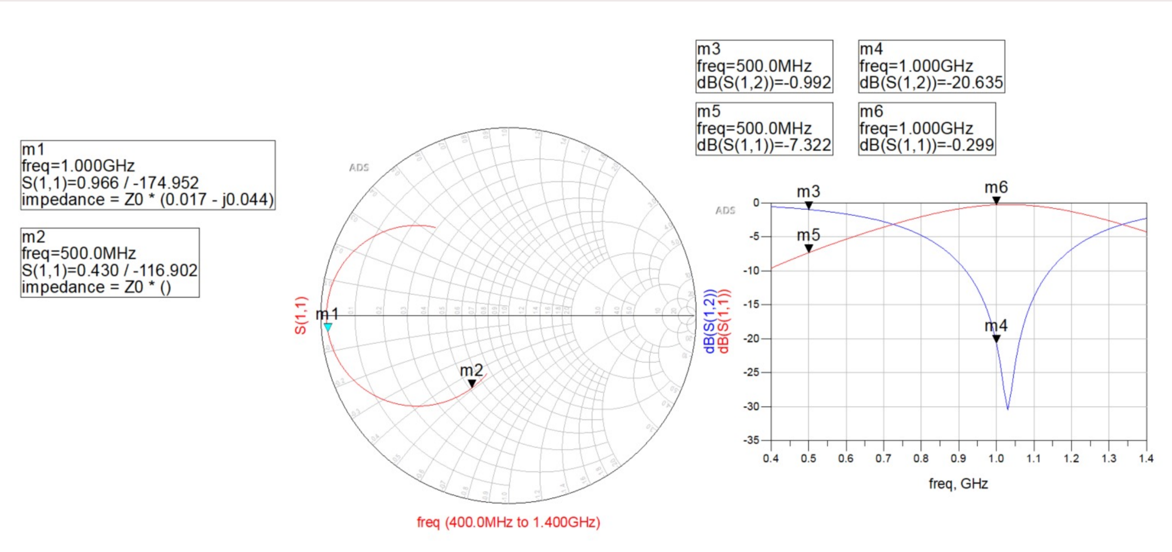
Reflected wave $\left(l = \frac{\lambda}{2}\right)$

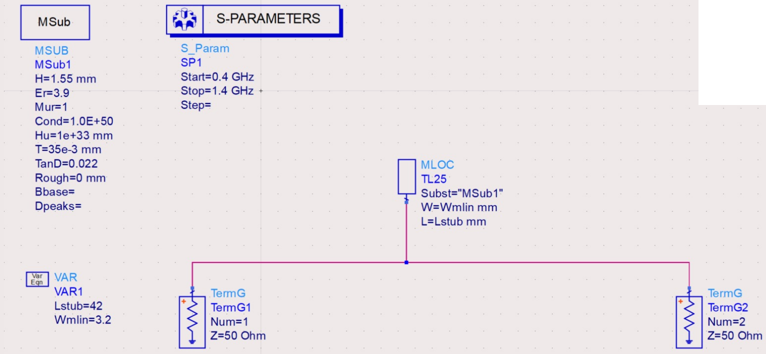


No current flow!

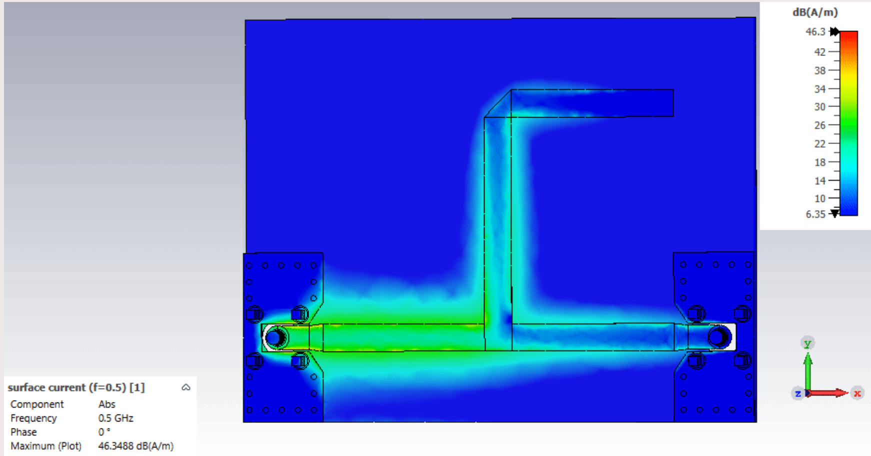
What is the reflection coefficient?

Lab assignment

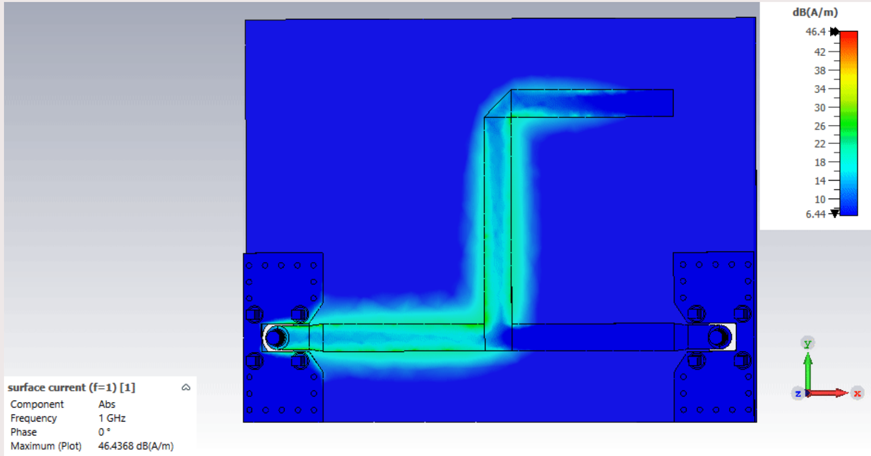




Current flow quarter-wave stub



Current density simulation model open stub for f=500 MHz



Current density simulation model open stub for f=1 GHz

Lab assignment

Answer the following questions:

Don’t forget to export your data!

1. See the simulation results on the previous slide. How do these results relate to the absorbed and/or reflected power?
2. Measure the reflection coefficient. What do you expect? Do the simulations on the previous slide agree with measurements? If not, what can be the cause of that? Look at both the Smith chart and the LOGMAG plot.
3. What kind of transmission line type is used for this stub (e.g. coax, stripline, coplanar waveguide, Microstrip etc.)
4. Determine the characteristic impedance Z_0 of the stub. Explain how you get to your answer!
5. Determine the magnitude and phase of the reflection coefficient of the component at 1 GHz. Import these results into Matlab!
6. What is the impedance seen from port 1?
7. What kind of application can this passive component be used for?

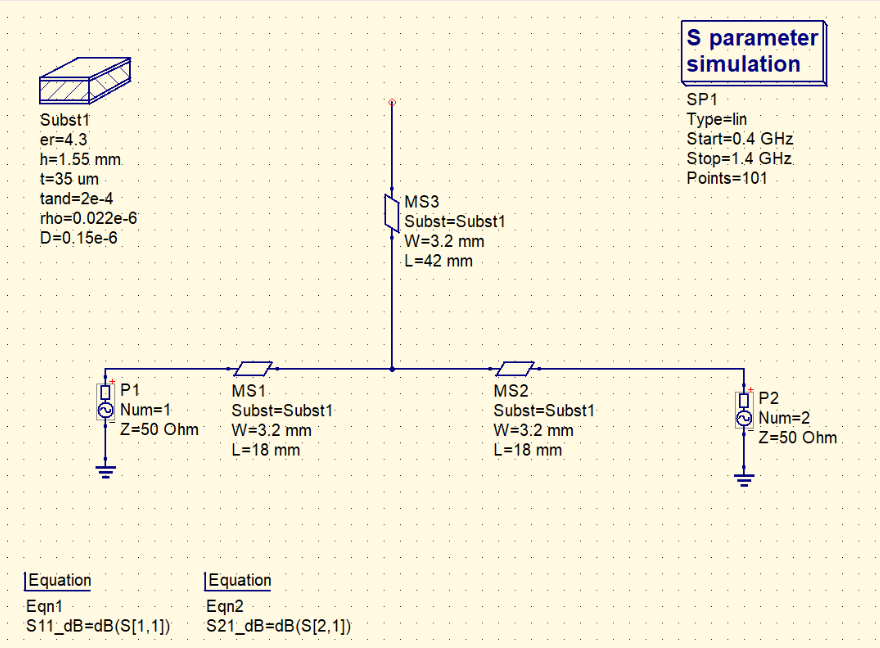
Lab assignment

Answer the following questions:

1. Draw the quarter-wave stub in QUCS (see figure)

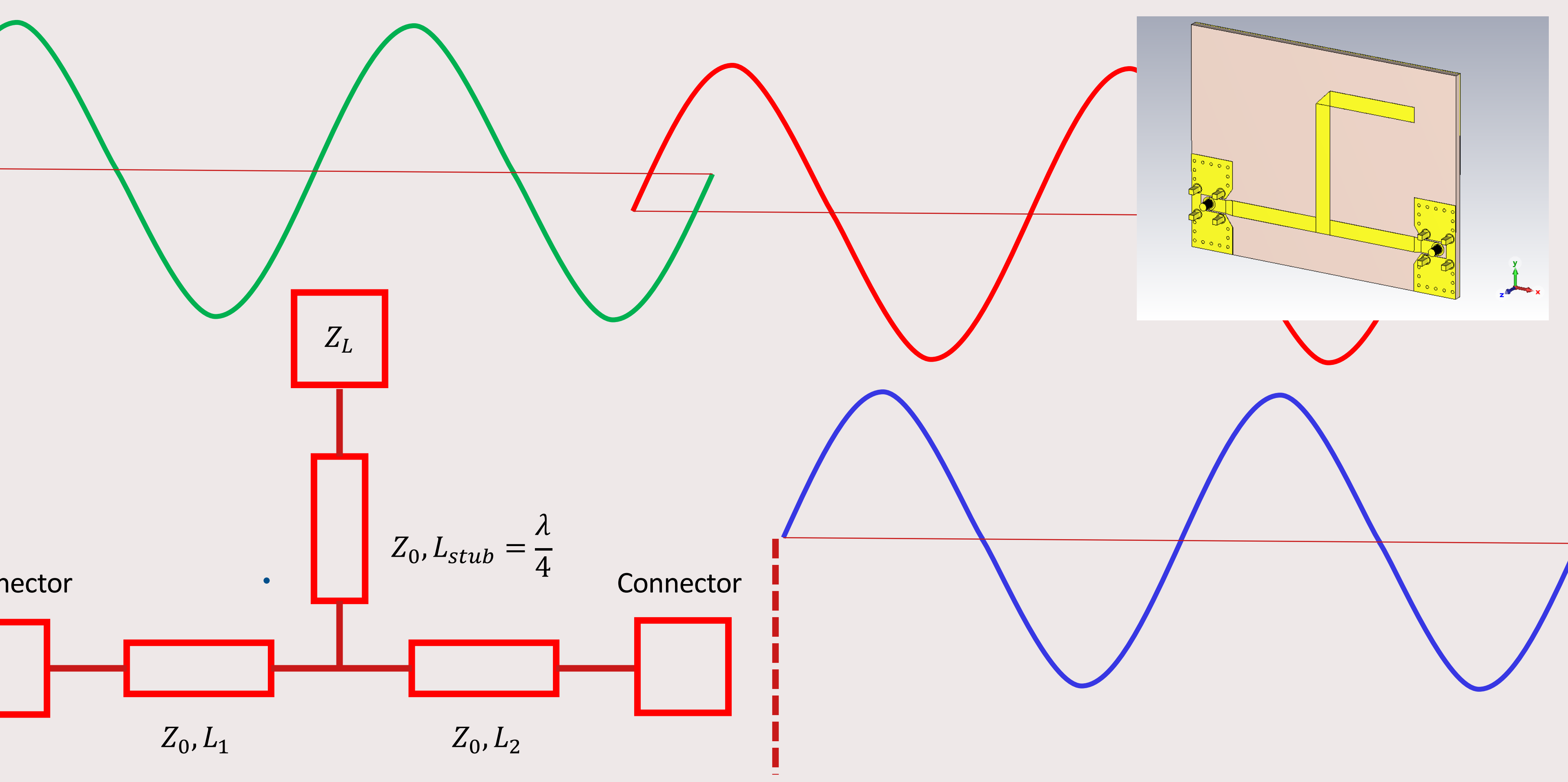
2. Do the simulations agree with the S-parameters of your measurement? If not, what could be the cause of that?

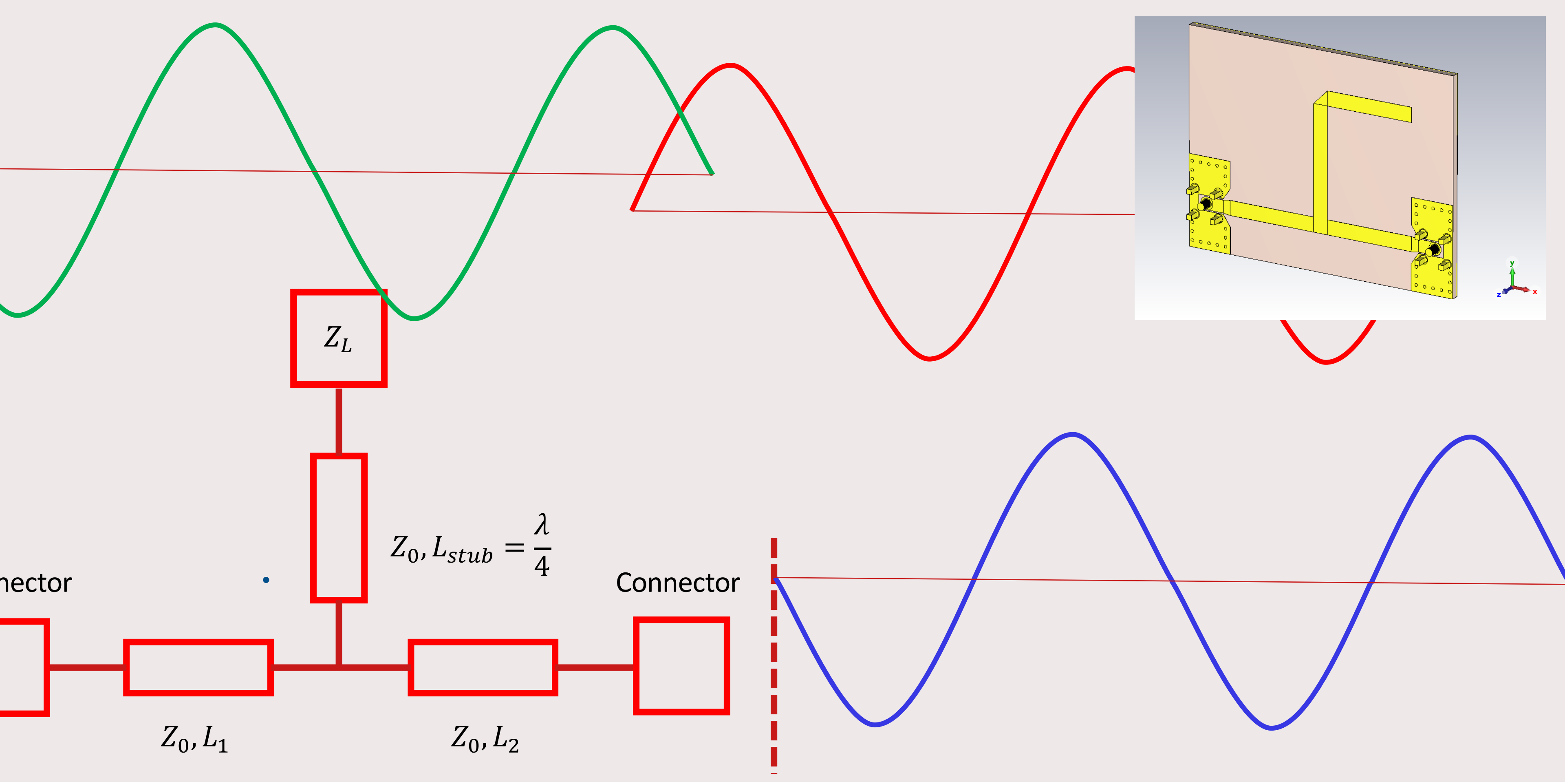
3. What happens if your stub is a short-circuited stub? Explain what happens with your S11 and S21



Manual NanoVNA

A manual on how to use the NanoVNA can be found at CANVAS
“5XTC0 Labs 2021 2022 - Using the NanoVNA”


Z_L
$Z_0, L_{stub} = \frac{\lambda}{4}$
nector
Connector
Z_0, L_1
Z_0, L_2
Port 2


Z_L
$Z_0, L_{stub} = \frac{\lambda}{4}$
nector
Connector
Z_0, L_1
Z_0, L_2
Port 2